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Reconstructed Marine Fisheries Catches at a Remote Island Group: Pitcairn Islands (1950–2014)

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The remote Pitcairn Island Group in the South Pacific was designated one of the world's largest marine reserves in 2016, encompassing some of the few remaining near-pristine areas within EEZ boundaries. Pitcairn's domestic fisheries are small-scale, and consist mainly of subsistence (non-commercial) and limited artisanal (commercial) catches. There is no locally-based industrial (large-scale commercial) fishery and the level of foreign industrial activity in recent times has been minimal, due in part to the low biomass of commercially valuable species, along with economic constraints of the EEZ's geographic isolation. Using a catch reconstruction method we estimated the total domestic marine catches for the Pitcairn Islands from 1950 to 2014. We show that overall the Pitcairn Islands' small-scale fisheries catches were almost 2.5 times higher than the data reported by the Food and Agriculture Organization (FAO) of the United Nations on behalf of the Pitcairn Islands, however, this primarily reflects discrepancies prior to the 1980s. Overall, catches for the subsistence and artisanal sectors started with around 12 t·year⁻¹ in 1950, but declined to 4 t·year⁻¹ by 2014. Domestic reconstructed subsistence catch levels were entirely driven by changes in the human population on the island, with reconstructed artisanal catches only occurring in recent years (2000 onwards). Industrial fishing is entirely executed by foreign vessels, this catch is considerably variable throughout the years and ceases entirely in 2006. The implementation of one of the world's largest marine reserves surrounding the offshore waters of Pitcairn Island has been specifically designed not to affect the rates of subsistence and artisanal fishing conducted by the resident population. Although there is no industrial fishing in the Pitcairn EEZ at present, climate change is predicted to influence the routes of migrating commercially-targeted species, potentially altering fishing effort levels and shift target fishing zones. Implementation of MPAs such as the Pitcairn Island Marine Reserve protect large oceanic areas from risk of future industrial exploitation, whilst protecting near-shore reef and deep-water zones, maintaining domestic coastal fisheries vital for local communities.

Keywords: unreported catches, artisanal fisheries, subsistence fisheries, small-scale fisheries, marine protected area, exclusive economic zone

INTRODUCTION

Marine Protected Areas (MPAs) are a well-recognized and increasingly utilized tool for managing and protecting marine ecosystems from the existing or potential impacts of anthropogenic activities. In 2010, the Convention on Biological Diversity called for formal protection of at least 10% of the world's marine and coastal areas by 2020, under Aichi Biodiversity Target 11¹. Much of the progress toward this target is being attempted through the establishment of very large MPAs (>100,000 km²), with ~62% of the total global marine area under protection contained within 24 such MPAs (Jones and De Santo, 2016). A trend of establishing these very large MPAs in locations described as “residual” to extractive or commercial uses has also been identified (Devillers et al., 2015). These observations have led to concerns that emphasis on meeting conservation targets through coverage in square kilometers or political “ease of establishment” (Devillers et al., 2015) is resulting in additional Aichi target objectives (such as reserve connectivity and representativeness) being side lined (Singleton and Roberts, 2014; Devillers et al., 2015; Jones and De Santo, 2016). Given that the expansion of fishing to newly exploited areas has declined since its peak in the 1980s (Swartz et al., 2010), it is likely that areas currently considered “residual” to fishing have already been determined unviable based on failed fisheries or low assessed catch. Fishery resource assessments are performed by projects such as the Skipjack Survey and Assessment Programme by the South Pacific Commission (Dalzell et al., 1996). The low fisheries activity in these remote areas is therefore more likely a result of other causes, such as low biomass of commercially valuable species, or economic constraints such as distance from markets. With changes to catch potential projected under climate change scenarios (Cheung et al., 2010), and shifts in the species being targeted by industrial fleets (Pauly and Palomares, 2005), understanding the historic and underlying causes of why an area is not targeted by commercial fisheries can provide insights into how MPAs may function in the context of future fisheries and conservation objectives.

In 2016, the United Kingdom designated the waters surrounding its sole Pacific Overseas Territory, the Pitcairn Islands' group, as one of the world's largest marine reserves (Figure 1). Located in the central South Pacific, the Pitcairn Islands are among the most remote on the planet (Dawson, 2015), with their nearest neighbor, the Gambier Islands' group of French Polynesia, being 390 km to the north-west. Despite having a relatively small combined land area of 49 km² (Irving and Dawson, 2012), the farthest two islands in the Pitcairn group are separated by a distance of ~560 km (Irving and Dawson, 2012), resulting in an Exclusive Economic Zone (EEZ) of over 836,000 km²². Of the four islands within the Pitcairn Islands' group, only Pitcairn Island itself is inhabited by people, with two

of the remaining islands (Oeno and Ducie atolls) being relatively untouched (Irving and Dawson, 2012); and Henderson Island a World Heritage Site as one of the last near-pristine elevated atolls in the world (UNESCO)³. The reserve is designed to allow the continuation of small-scale fishing by the local population by excluding the waters up to 12 nautical miles (or ~22 km) offshore from each of the four islands, along with a corridor of ocean connecting Pitcairn Island to a nearby seamount, locally known as 40 Mile Reef. The remaining EEZ is encompassed in a total no-take area, covering over 830,000 km² of ocean (Dawson, 2015).

The purpose of this study was to utilize the available information on fishing by the subsistence, artisanal and (foreign) industrial fisheries operating within the Pitcairn Island EEZ or EEZ-equivalent waters (prior to EEZ declaration), in order to reconstruct best estimates of total fisheries catches from 1950 to 2014, using the well-established catch reconstruction method (Zeller et al., 2016). We also compared the reconstructed domestic catch estimates to the official statistics for the Pitcairn Islands presented on behalf of the United Kingdom's territory by the Food and Agriculture Organization (FAO) of the United Nations. We then considered the historical and on-going levels of catch for the Pitcairn Islands within the context of implementing large-scale marine reserves in remote, and fisheries residual areas.

METHODS

Exclusive Economic Zone (EEZ)

The Pitcairn EEZ (based on the *Sea Around Us* spatial database, Pauly and Zeller, 2015) was established in 1997, has a total area of over 836,000 km² (Figure 1), and a very small shelf area of 155 km².

Human Population Data

Human population trends for Pitcairn Island were primarily derived from the Pitcairn Study Centre census database⁴ and The World Factbook⁵. We linearly interpolated between data points to estimate population time series for 1950–2014. As of 2014, only 49 inhabitants resided on Pitcairn Island (Leguerrier et al., 2014), with a relatively steady decline from 163 residents in 1943.

Subsistence Fisheries

We followed the definition of subsistence fisheries outlined by Zeller et al. (2016) as “those fisheries that often are conducted by women and/or non-commercial fishers for consumption by one's family... [along with] the fraction of the catch of artisanal boats that is given away to the crews' families or the local community.” Subsistence *per capita* catch rates were estimated for Pitcairn Island and applied to human population data to estimate the total

¹Convention on Biological Diversity. Available online at: www.cbd.int/sp/targets/rationale/target-11 (Accessed 24 April 2017).

²*Sea Around Us*. Available online at: <http://www.seaaroundus.org/data/#/eez/612?chart=catch-chart&dimension=taxon&measure=tonnage&limit=10> (Accessed 2017 April 27).

³UNESCO World Heritage Centre. “Henderson Island”. Available online at: <http://whc.unesco.org/en/list/487> (Accessed 2016 May 28).

⁴Pacific Union College (2011) “Pitcairn Islands Study Centre: Census Data”. Available online at: <http://library.puc.edu/pitcairn/pitcairn/census.shtml> (Accessed: 2016 May 26).

⁵Central Intelligence Agency. “The World Factbook: Pitcairn Islands” (2016). Available online at: <https://www.cia.gov/library/publications/the-world-factbook/geos/pc.html> (Accessed 2016 May 26).

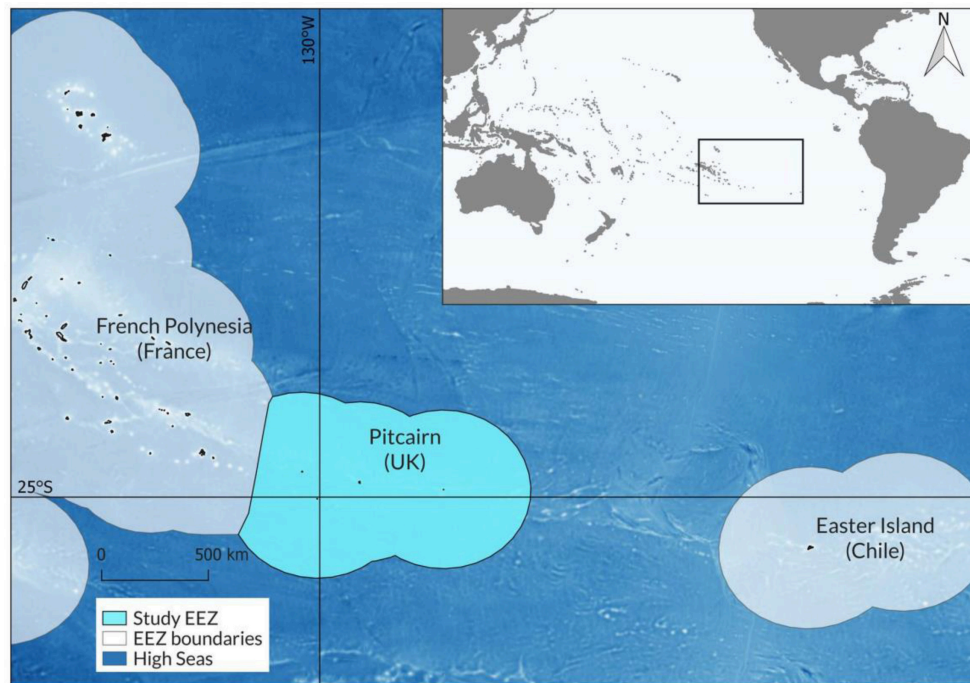


FIGURE 1 | The Exclusive Economic Zone (EEZ) of the Pitcairn Islands, an overseas territory of the United Kingdom (UK), and the EEZs of neighboring French Polynesia (a territory of France) and Easter Island (a territory of Chile), with surrounding High Seas.

annual subsistence demand. We conservatively assumed that all catch is landed with no discards due to the non-commercial nature of a subsistence fishery, expecting that all landed catch is utilized and all unwanted catch is released alive. Considerable information on fisheries and subsistence catches in the Pitcairn Islands' waters was derived from Gillett (2009), Adams and Langley (2005), Götesson (2012), and Irving and Dawson (2012). Catch rates were derived from the answers provided by 90% of the island's population ($n = 22$) to an unpublished survey in 2011 on the frequency and amount (kg) consumed per household, with mean consumption of $71.5 \text{ kg} \cdot \text{person}^{-1} \cdot \text{year}^{-1}$. Although Gillett (2009) estimated consumption at $140 \text{ kg} \cdot \text{person}^{-1} \cdot \text{year}^{-1}$, this was not based on data from the islanders, and considerably less fish was consumed by islanders in recent years. This is due to a declining number of fishers and an increased access to alternative sources of protein through a freight shipping service to Pitcairn from New Zealand which has been operating since 2002. Meanwhile, Dalzell et al. (1996) reported 8 tons of subsistence catch for Pitcairn between 1989 and 1994, which amounts to $1.6 \text{ t} \cdot \text{year}^{-1}$, although it is not clear how this estimate was derived. Here, we chose the more conservative estimate, although the previous reconstruction by Chaitanya et al. (2012) used that provided by Gillett (2009). As there was limited information indicating how consumption rates have changed over the study time period, we fixed the consumption rate of $71.5 \text{ kg} \cdot \text{person}^{-1} \cdot \text{year}^{-1}$ back to 1950.

Once the total subsistence catch for the island was estimated, we approximated the species composition with information from Gillett (2009), Sharples (1994), Adams and Langley (2005),

Götesson (2012), and Dalzell et al. (1996). Our breakdown included miscellaneous invertebrates and fishes as well as specific species, genera and families. Due to the large variety of snappers (Lutjanidae) and groupers (Serranidae) that were caught, we did not break this down further besides the highly targeted *Epinephelus fasciatus*, *Variola louti*, and *Kyphosus pacificus*; spiny lobster (*Panulirus* spp.—essentially *Panulirus pascuensis* and *Panulirus penicillatus*), and slipper lobster (*Scyllarides haanii*). The taxonomic breakdown was separated into two periods, 1950–2003 and 2004–2014. From 1950 to 2003, no lobster catch was consumed by islanders due to the religious influence of the Seventh Day Adventist Church on their diets. However, within the 10 year period from 2004 to 2014, this influence decreased and lobster catch increased for both artisanal sale and personal consumption, with a recent decrease in lobster catch possibly related to localized depletion (Götesson, 2012).

Between 1976 and 1996, catch data consisting of number of fish caught each month were sporadically recorded in the local newsletter, the *Pitcairn Miscellany* (Gillett, 2009; Götesson, 2012; Duffy, 2014); with the island's fishing and diving club recording catch into the 2000s (Duffy, 2014). However, as no size parameters were recorded and the purpose of the landings (subsistence or artisanal) was not available, we were unable to use these data here.

Artisanal Fisheries

Artisanal fishing is defined as predominantly commercial catch taken by small-scale and fixed gears (Zeller et al., 2016). Due to the small-scale nature of artisanal fishing we assumed that all

catch is sold, given away, or released, resulting in no discarded catch. Irving and Dawson (2012) indicated that around four cruise ships purchased on average ~ 600 kg of tuna, wahoo, and reef fish, and 400 kg of lobster. Artisanal fisheries sales to cruise ships occur on an *ad-hoc* basis, with the sales noted by Irving and Dawson (2012) probably first occurring around 2000. The artisanal sale of lobster to certain visiting cruise ships began about 10 years ago (Michel Blanc, Fisheries Development Adviser, Pacific Community, pers. commun. 2011). Gillett (2009) suggested that Pitcairn's artisanal fisheries catch may amount to ~ 5 t-year⁻¹, which is five times that derived from the four ship orders observed by Irving and Dawson (2012). Gillett (2009) based his estimation on an assumption that artisanal catch would likely be less than that which the islanders consumed themselves, but still of some financial value, providing no other grounds for this tonnage. Artisanal catches from the cruise ship orders observed by Irving and Dawson (2012) provided the more conservative estimate of artisanal catch (although did not include the likely trade of smaller amounts to other vessels), and were used here. Note that this differs from the estimates provided by Gillett (2009), which were used in the previous reconstruction by Chaitanya et al. (2012). Estimates can also be derived through other means, such as the annual return of a fishery and the known price for which fish are sold. According to Sharp (2011), the Pitcairn islanders were earning about US \$12,800 per year in revenue through the sale of fish to cruise ships. The wholesale fish price of US \$8 kg⁻¹ in nearby Mangareva estimated by Sharp (2011), was applied to ~ 1.6 tons of miscellaneous fish sold to cruise ships each year. This is 0.6 tons more than the amount from observed cruise ship orders. Note that Götesson (2012) states fish were usually sold at USD \$5 kg⁻¹, and lobsters for USD \$10 kg⁻¹, which gives an average price of around USD \$7 kg⁻¹, similar to the USD \$8 kg⁻¹ suggested by Sharp (2011). Assuming the catch breakdown of 40% lobster and 60% fish (from the average cruise ship orders mentioned previously) applies to other artisanal sales, at USD \$5 kg⁻¹ and USD \$10 kg⁻¹, respectively: a total revenue of USD \$12,800 would result from a sale of 0.64 tons of lobster and 1.5 tons of fish, totaling 2.2 tons of catch. We used the most conservative estimate of 0.6 t-year⁻¹ before lobster was caught and 1 t-year⁻¹ after, as this is the only approximation based on a given commercial order rather than derived from estimated revenue and estimated sale prices. Cruise ships have visited the islands since 1914 in relatively consistent numbers⁶, alongside privately owned yachts and other passing vessels. Despite this, in a comprehensive review covering hundreds of accounts of trade and barter between Pitcairn Islanders and passing vessels, fewer than a dozen mentions were made of fish being provided or sold (Herb Ford, 2017, pers. commun. 31st May). Rather, vessels visiting Pitcairn were often well stocked with meat, with the main commodities procured by ships during visits being wood, water and fruit (Herb Ford, 2017, pers. commun. 31st May). According to Dalzell et al. (1996) there were no artisanal fish sales for the Pitcairn Islands in the early 1990s. However, by 1994 instances of fish being traded with

cruise ships had been noted (Sharples, 1994), although there is no information on the frequency or quantity of fish traded. To provide a conservative estimate, we assumed all catch was landed and chose to limit our reconstruction of artisanal fisheries to 1999 onwards, with no artisanal sales estimated before this point. Lobster catch (0.4 t-year⁻¹) was only included for the final 10 years of the reconstruction, with 0.6 t-year⁻¹ of artisanal fish catch held constant from 2000 until the inclusion of lobster in 2004, and 1 t-year⁻¹ of the same ratio of fish to lobster held constant until 2014.

The species breakdown for the artisanal fishery was primarily based on Irving and Dawson (2012); tonnage was split evenly between tuna (*Thunnus* spp.), wahoo (*Acanthocybium solandri*), reef fish ["marine fishes not elsewhere included (nei)"], and lobsters (*S. haanii*. and *Panulirus* spp.). We did not separate tuna into species. While the islanders primarily catch yellowfin tuna (*T. albacares*), they also catch skipjack tuna (*Katsuwonus pelamis*) with occasional landings of albacore tuna (*T. alalunga*) and bigeye tuna (*T. obesus*) (Adams and Langley, 2005; Götesson, 2012; Irving and Dawson, 2012; Duffy, 2014). We did not assign specific tonnages to individual reef fish species due to the high species variety and relatively low tonnages. However, common taxa include *K. pacificus*, *V. louti*, and *Epinephelus tauvina* (Irving and Dawson, 2012). Data on shark catches are sporadically available, but there is little information on the consistency of the targeting of sharks by local fishers over time. Nonetheless, there is some indication that the fishing pressure on sharks around Pitcairn Island, when compared to the remaining islands, may be considerable according to a study by Duffy (2014). From the data available, Götesson (2012) reports 714 sharks were caught through the years 1977–1997 and 12 sharks caught in the year 2008. Duffy (2014) stated data on shark catches were collected for 20 months over 2006–2008 by the community, with 28 sharks being caught during this period. As some recorded years have a zero count for shark catch, we felt we were unjustified in extrapolating shark catches beyond the years for which we had data. As sharks are primarily targeted for their teeth which are used in carvings, mainly small sharks are caught, including juveniles (Götesson, 2012; Duffy, 2014), making an average weight of the sharks caught difficult to estimate, and thus estimated landed tonnages difficult to derive. In order to remain conservative, we excluded shark catch from our reconstruction, despite the potential for this contribution to be substantial to the overall yearly catch and artisanal catch composition.

Industrial Fisheries

According to Adams and Langley (2005), very little industrial fishing occurred in the area of their study, which included the Pitcairn EEZ ($\sim 50\%$ of the total study area) and surrounding areas. Adams and Langley (2005) suggested this is a consequence of the islands being farther south than the distribution of pole-and-line and purse-seine fleets, with the only industrial fishing activity in this area being performed by foreign longliners. To remain concise and focused on domestic fisheries we do not detail discards in this analysis, this is due to the complexity of multiple foreign fishing entities using a variety of gears in the Pitcairn EEZ since 1950. The discard rates are dependent on the

⁶Pitcairn Islands Office. "Pitcairn's History." Available online at: <http://www.government.pn/Pitcairnhistory.php> (Accessed 2016 May 27).

country fishing, target species and gear used, these discards along with the rest of the industrial catch was estimated in a separate analysis (see Le Manach et al., 2016). Industrial fishing vessels were not based at the Pitcairn Islands, as the existing harbor is too small for berthing, there are no processing facilities and no exporting opportunities (e.g., no airport on the island). Foreign industrial fishing within the waters of the Pitcairn Islands began in the 1950s with Japanese longliners targeting tuna, followed in the 1960s by industrial fleets from Taiwan and Korea (although China and French Polynesia were said to fish in the vicinity as well), these peaking in the early 1970s, with the Japanese and Korean fleets largely by-passing the Pitcairn Islands from the 1980s onwards (Adams and Langley, 2005; Irving and Dawson, 2012). According to Gillett (2009), there is only one accessible document noting the historic allowance of foreign vessels in the Pitcairn Islands EEZ, an access agreement that permitted up to 20 Japanese longliners to operate within the waters of the Pitcairn Islands. Gillett (2009) also revealed that the most recent access agreement in 2006 was for a longliner (of unspecified nationality) with a single fee of \$1,000 (resulting in less than a week's fishing), although this information was provided to Gillett (2009) by personal communication and is not available elsewhere. The Forum Fisheries Agency (2008) produced a single report that contained data on tuna catch in the waters of the Pitcairn Islands, with 5 tons of albacore (*Thunnus alalunga*) caught by a foreign (unnamed) longline vessel in 2005 (Gillett, 2009). The global industrial catch of large-pelagic fish was reconstructed as a separate data layer by the *Sea Around Us* (Le Manach et al., 2016).

Reconciling Reported Data with Reconstructed Estimates

Data from the FAO of the United Nations (FAO, 2016) were used as the reported data baseline for the domestic fisheries. We assigned reported catches as being artisanal in nature. When more than our estimated artisanal catch ($0.6\text{--}1\text{ t}\cdot\text{year}^{-1}$) was said to be reported, we assumed the FAO catch amounts included subsistence catch. Any remaining estimated catch was then assigned as unreported catch. Thus, we assumed that 100% of artisanal catches were deemed reported. For foreign industrial fisheries, reported landings were based on the spatially allocated global reconstructed catch database of the *Sea Around Us* (Zeller et al., 2016).

RESULTS

Total Reconstructed Catches

Overall, reconstructed catches for Pitcairn Island, which consist of subsistence and artisanal sector catches, totaled about 418 tons for the period 1950–2014 (Figure 2A). This reconstructed catch was almost 2.5 times more than the 173 tons reported by FAO on behalf of the Pitcairn Island for the same time period (Figure 2A). Nevertheless, our reconstructed catches correspond more closely with those reported to FAO from the 1980s onwards, this agreement is likely due to a “presentist” bias of improving data quality over the years as described in Pauly and Zeller (2017). Given the close linkage between the (declining) human population and domestic catches, along with the decline and

eventual cessation of foreign industrial catch (see below), it is not surprising that total catches declined steadily over the time period examined. Subsistence catches dominated the domestic reconstructed catch, accounting for ~97% of the reconstructed total catch (decreasing to ~78% by 2014 when the population had dropped to 49 people), while artisanal fishing accounted for ~3%. With no domestic industrial fisheries, foreign industrial catch accounted for all large-scale fishing activity, showing substantial fluctuations in catch until the end of this activity in 2006 (Figure 2B).

Subsistence Catches

Overall, reconstructed subsistence catches totaled 406 tons between 1950 and 2014. Subsistence catches fell throughout this period due to the declining population, with average catch declining from 12 to ~4 $\text{t}\cdot\text{year}^{-1}$ by 2014 (Appendix 1 in Supplementary Material). Fluctuations in our reconstructed catches over this time period are entirely due to human population fluctuations, as alternative sources of variations in subsistence catch (such as poor weather) were not considered in our estimation. Subsistence catches were dominated by *E. fasciatus*, *V. louti*, and *K. pacificus*, while general Lutjanidae, Serranidae, and “marine fishes not elsewhere included (nei)” also occurred in the catch throughout the entire time period (Appendix 2 in Supplementary Material). Catches after 2003 included “miscellaneous aquatic invertebrates,” representing *S. haanii* and *Panulirus* spp.

Artisanal Catches

Artisanal catches totaled 13.4 tons over the 1950–2014 period, derived from an estimated catch of $0.6\text{ t}\cdot\text{year}^{-1}$ from 2000 to 2003, followed by $1\text{ t}\cdot\text{year}^{-1}$ from 2004 to 2014 (based on our assumptions, see Appendix 1 in Supplementary Material for data). Transportation issues, erratic weather patterns, rough seas, and a lack of tourist accessibility to the island likely contributed to fluctuations in the annual catch that could not be reflected here due to insufficient data on these variables. Artisanal catch consisted exclusively of finfish from 2000 to 2004, after which we included 40% of the catch as crustaceans. Total tonnage in recent years was split evenly between slipper lobster (*S. haanii*), spiny lobster (*Panulirus* spp.), tuna (*Thunnus* spp.), wahoo (*A. solandri*), and reef fishes (“marine fishes nei”).

Foreign Industrial Fisheries

While there was some foreign fishing in Pitcairn waters in the early years of our study period, from 2006 onwards there appears to have been no major industrial fishing activity within the EEZ (Figure 2B). Throughout the time period of this reconstruction, there is some fluctuation in foreign catches, with foreign catches appearing to be very low in the 1950s and early 1960s. Foreign catches in the EEZ increased to between 5,000 and $12,000\text{ t}\cdot\text{year}^{-1}$ in the 1960–1980s, but remained highly variable (Figure 2B). Foreign fishing seemed to have declined substantially in the 1990s, before ceasing in the mid-2000s (Figure 2B).

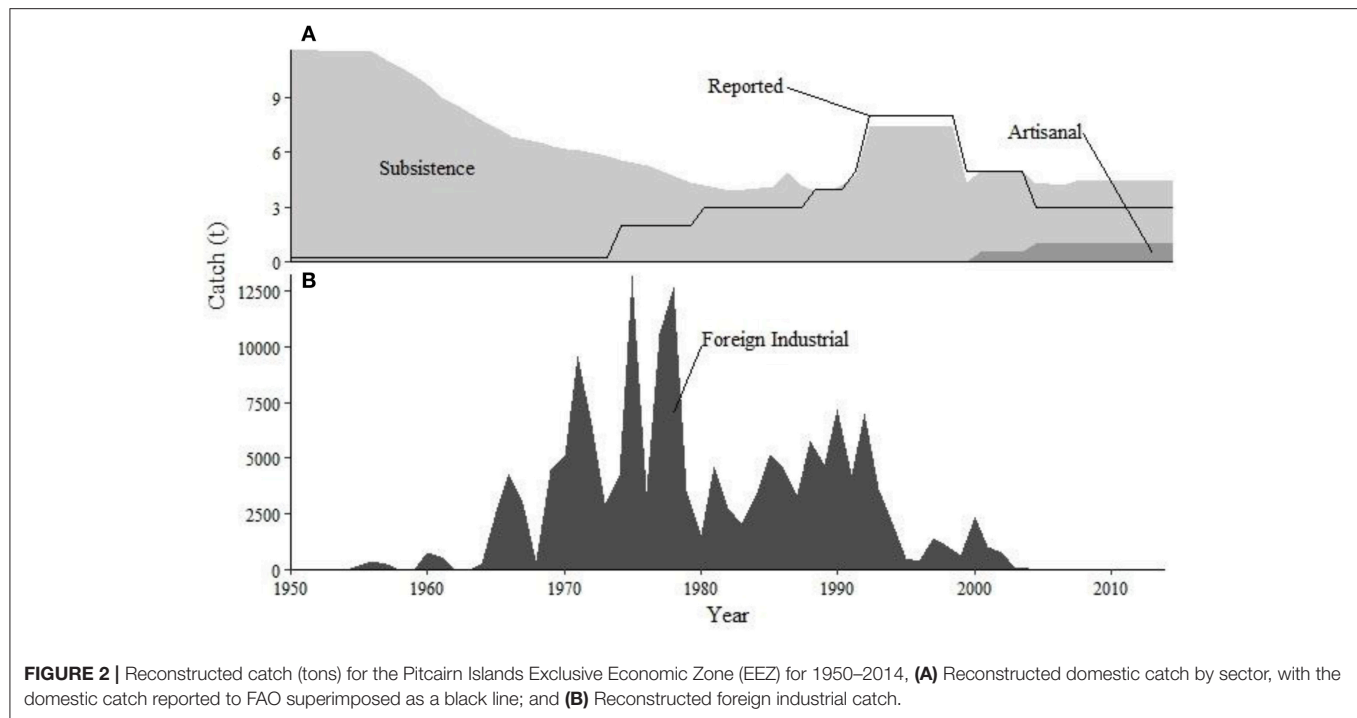


FIGURE 2 | Reconstructed catch (tons) for the Pitcairn Islands Exclusive Economic Zone (EEZ) for 1950–2014, **(A)** Reconstructed domestic catch by sector, with the domestic catch reported to FAO superimposed as a black line; and **(B)** Reconstructed foreign industrial catch.

DISCUSSION

Reconstructing Fisheries Catches

The reconstruction of total domestic fisheries catches for the Pitcairn Islands from 1950 to 2014 suggests that actual catches were likely almost 2.5 times greater than the data provided to the FAO at the beginning of the time period. As many of the Pacific Island countries and territories rely heavily on (mainly coastal) fish stocks for food security and livelihoods (Zeller et al., 2015; Charlton et al., 2016), appropriate monitoring, reporting, and management of coastal marine fisheries is vital for ensuring food and nutritional security (Golden, 2016; Golden et al., 2016). Our study illustrates the importance of accounting comprehensively for non-commercial fisheries catches (e.g., subsistence), as has also been shown for other Pacific island countries (Zeller et al., 2015). Small-scale fisheries, and especially non-commercial subsistence fisheries, are consistently under-represented in globally reported data (Pauly and Zeller, 2016), as are recreational catches (Smith and Zeller, 2016). While this is most prevalent in developing countries (Zeller et al., 2015), under-reporting also exists in highly developed countries (Zeller et al., 2011). We used information from a variety of sources including FAO, the Secretariat of the Pacific Community (SPC) and independent studies in the attempt to maximize reliability of data and information sources, however our estimates rely heavily on self-reporting and assumptions, and therefore are subject to limitations including underestimation and generalization.

With regards to artisanal fisheries, our catch estimation for the period 1950–2014 (totaling 13.4 tons) was ~22 times less than that of a previous, preliminary reconstruction attempt by

Chaitanya et al. (2012), who estimated 300 tons of artisanal catch over the same time period. This discrepancy is due to our more conservative use of the four large cruise ship orders as the baseline of artisanal catch, rather than the less conservative estimate of 5 t·year⁻¹ suggested by Gillett (2009) and subsequently used by Chaitanya et al. (2012). Our estimate of 0.6 t·year⁻¹ for artisanal catch from 2000 to 2004, and 1 t·year⁻¹ thereafter, is closer to the 1.6 t·year⁻¹ of artisanal catch which can be derived by dividing the estimated annual revenue of fish sales to cruise ships by the estimated cost per kilo of landed fish at the closest market in Mangareva (Sharp's, 2011). Even the alternative approach of applying Götesson's (2012) suggested market price to Sharp's (2011) revenue estimate (resulting in 2.2 t·year⁻¹) is closer to the conservative estimate we have used than that suggested by Gillett (2009).

Such low levels of artisanal catch compared to the yearly subsistence catch is unsurprising, as Gillett (2009) suggested that subsistence fisheries were of greater magnitude due to the remote nature of the islands. The development of the artisanal fisheries sector in the Pitcairn Islands has been constrained by a number of factors, including: a lack of transportation infrastructure (Amoamo, 2011), limited freezer storage facilities (Irving and Dawson, 2012), difficult and weather dependent accessibility (Irving and Dawson, 2012), distance from the nearest market (Adams and Langley, 2005), and the likely limited sustainability of the local near-shore fisheries resources themselves (Adams and Langley, 2005; Palomares et al., 2011). Furthermore, despite a recent increase in cruise ship visits, artisanal sales to these vessels is likely to decline in the near future due to health and safety restrictions, a lack of recognized provenance for the catches, and a declining population of fishers.

The subsistence catch shown here replicates the declining human population trend shown by Chaitanya et al. (2012), remaining constant from 2007 onwards when the population stabilized at ~48 people. The *per capita* estimate used in this reconstruction was derived from an unpublished survey based on levels of consumption in 2011 (Schuttenberg and Dawson, 2012). While comparing monthly catch data from 2008 to that collected a decade prior, Duffy (2014) noticed a decrease in catch amounts, despite no change in the population size. Duffy (2014) suggested that this decrease may be a consequence of the aging population. Additionally, as diet preferences have shifted over time, particularly recently with increased access to external food supplies from a regular supply ship, our estimate is likely to be rather conservative for earlier years. Under religious restrictions forbidding the consumption of certain taxa, lobsters were mainly caught for bait and artisanal sales, however, in more recent years lobsters have also become a part of some islanders' diets (Götesson, 2012). To remain conservative, we only included lobster catch in recent years (2004–2014). Meanwhile, stock sizes of sea chub (*K. pacificus*) were suggested to have increased in recent years (Götesson, 2012), with landings decreasing from an estimated 2.3 tons in 1950–0.6 tons in 2014 in our reconstruction.

While there has never been any domestic industrial fishing activity within the Pitcairn EEZ, some information is available on the foreign industrial fisheries operating within these waters. Japanese, Korean and Taiwanese industrial fishing boats have targeted yellowfin, big eye, and albacore tunas in Pitcairn's waters (Götesson, 2012). Specifically, in 1963 Japanese vessels were active in these waters targeting tuna, bonito, and mackerel, and in 1966 a South Korean vessel was active in the area. This foreign fleet activity peaked around 1975, with Japanese and Korean activities declining in the following 10 years. Catches were highly variable throughout the period of the study, including at the peak of the fishery (Götesson, 2012). Industrial fishing within the Pitcairn EEZ has been deemed to be economically unviable (Adams and Langley, 2005). Furthermore, an access agreement worth \$1,000 by an unknown fishing entity in 2006 reportedly only resulted in a few days of fishing (Gillett, 2009), and was not renewed, further suggesting the unviability of industrial-scale fishing in these waters at present. A recent remote monitoring trial (Jan. 2015–Mar. 2016) carried out by Project Eyes on the Seas on behalf of the UK government observed no vessels displaying illegal fishing behavior, suggesting likely little illegal fishing activity is occurring in the EEZ⁷.

The Pitcairn EEZ seems unsuitable for industrial fishing activities at present due to the low abundance of valuable species such as tuna (Adams and Langley, 2005). Furthermore, the low diversity of fish species resulting from the isolated location and distance from the equator (Friedlander et al., 2014) is likely to limit industrial interests at present. While Catch Per Unit Effort (CPUE) for albacore (*Thunnus alauunga*) within the wider vicinity

of the Pitcairn Islands from 1958 to 2002 was noted by Adams and Langley (2005) to be similar to the regional average, the largest hotspots for the cumulative longline catch from 1990 to 2003 were observed outside of the Pitcairn EEZ. Adams and Langley (2005) further noted the considerable temporal constraints on the tuna fisheries in the region, being limited by the short and unpredictable fishing season (~October to March), along with high inter-annual variability in landings. Such unpredictability in annual catch likely poses an investment risk to commercial fishing operations in such remote locations.

Implications for Large Oceans MPAs

Given that historical levels of industrial, artisanal, and subsistence fishing activities have never been substantial in the Pitcairn EEZ, and that industrial fisheries have ceased altogether, it is reasonable to describe the Pitcairn EEZ as an area that is currently "residual" to fishery interests. One of the arguments proposed against investing in the establishment of remote large MPAs is that such reserves may provide little protection to the species and ecosystems currently impacted by anthropogenic activities (Devillers et al., 2015). However, the cause of unprofitable fisheries resulting in "residual areas" need not always be the lack of target species biomass, and may instead reflect economic (e.g., cost) or technological constraints which are subject to change.

Historical reconstructions of fisheries can provide insights into why fisheries never developed or stalled in these residual regions, which may be of value when determining whether an ecosystem is at risk of future exploitation. Data on fisheries landings from the FAO alone do not provide a whole picture of whether an ecosystem is indeed heavily fished, as FAO statistics report what the UK sent them on behalf of Pitcairn. While in the case of the Pitcairn Islands' waters, artisanal and industrial fisheries have likely been constrained by low biomass of commercially valuable species, some species (such as sharks) have likely been safeguarded from exploitation by their distance from markets, as opposed to the levels of their abundance. Ducie Island in particular exhibits high top predator biomass, accounting for 62% of the total fish biomass (or ~1 ton per hectare) (Friedlander et al., 2014). Overall, 46% of top predator biomass in the Pitcairn Island group was comprised of gray reef sharks, followed by whitetip reef sharks at 12% (Friedlander et al., 2014). So long as the value of shark products remains high, coupled with decreasing biomass in heavily fished areas (Worm et al., 2013), even remote or previously untargeted regions may be at risk of opportunistic shark fishing.

The data discrepancies between the reported FAO data and the reconstructed catch have greatly decreased since the 1980's, showing an improvement in fisheries data collection, despite this, local surveillance, and enforcement in the area may still be weak. Thus, although there is some evidence of sharks caught around Pitcairn Island, it is unclear how much fishing pressure they have faced around Ducie, Oeno, and Henderson Islands (Duffy, 2014). The elevated shark biomass around Ducie Island is correlated to high coral coverage (56%), a drastically different marine environment compared to Pitcairn Island, which has the lowest coral coverage (5%) and is instead 42% covered by

⁷ Pew Charitable Trusts Fact Sheet (2016). Effective Surveillance in the waters of the Pitcairn Islands Marine Reserve. Available online at: <http://www.pewtrusts.org/en/research-and-analysis/fact-sheets/2016/09/effective-surveillance-in-the-waters-of-the-pitcairn-islands-marine-reserve> (Accessed 2017 April 20).

erect macroalgae (Friedlander et al., 2014). The difference in habitat surrounding the four islands in the Pitcairn EEZ gives an uncertainty to the degree in which fishing pressure has effected fish composition and levels of biomass of Pitcairn Island compared to the remaining uninhabited islands. Regardless, shark biomass is substantially lower surrounding Pitcairn Island (Friedlander et al., 2014) and particularly juvenile individuals are subject to targeted fishing (Duffy, 2014), thus new regulations have been proposed to completely ban shark fishing and provide an alternative source for shark teeth (the primary fishing reason), such as through beach collections and aquariums (Dawson et al., 2017). Despite local shark fishing, the Pitcairn Island group's remoteness and small human population, in particular the distant unpopulated islands, cultivates a minimal risk of small-scale fisheries exploitation. The main focus of this MPA however, is not aimed at near-shore small-scale fisheries, but rather offshore industrial fisheries. Given the industrial catch in the Pitcairn EEZ has been highly variable since the 1950's, peaking at around 12,000 t-year⁻¹ in the mid-70's, the implementation of the Pitcairn marine reserve provides refuge for these high-value target species from future industrial exploitation.

A comprehensive report on the potential impacts of climate change on the ecosystems of Pacific Island countries (Bell et al., 2011) projected varying impacts on different fish functional groups. The demersal and invertebrate species targeted by the islanders' small-scale fisheries such as snappers and slipper lobsters are predicted to decline in productivity across this region due to reduced currents, increased sea surface temperatures, habitat loss, and ocean acidification (Bell et al., 2011). Meanwhile, Bell et al. (2011) suggest that tuna stocks may increase within Pitcairn's waters due to climate-driven shifts in the distributions of these taxa (see also Cheung et al., 2009). Adams and Langley (2005) indicated that catch of albacore tuna within the Pitcairn Islands EEZ generally coincided with seasonal variability in oceanographic conditions, with low catches associated with cooler water and higher catches with sea surface temperature increases. Changes to the sea surface temperature and current strength in the South Pacific gyre are anticipated in the coming decades, likely resulting in shifts in the distribution of large pelagic fishes (Bell et al., 2011). As tuna stocks have previously been targeted in the Pitcairn EEZ (Götesson, 2012) and been shown to have high levels just outside of the EEZ (Adams and Langley, 2005), it is likely these projected temperature changes could promote higher levels of tunas in the area, notably within the economic zone, as predicted by Bell et al. (2011).

Projected increases in sea surface temperature and ocean acidification may not only increase tuna production within the EEZ but in combination with the projected negative impacts on demersal and invertebrate species (Bell et al., 2011), could force the Pitcairn islanders to target more pelagic species such as tunas for subsistence, rather than the currently targeted reef fishes. As the fishing pressure is unlikely to increase due to the small and aging population (Duffy, 2014), fishers may have to change fishing tactics and sacrifice the profits from traditionally artisanal catch to feed their families. The proposed MPA regulations to ban shark fishing and provide an alternative

source for shark teeth could help mitigate these combined effects of climate change and fishing pressure on sharks whilst still providing a livelihood to the fishers (Dawson et al., 2017). Coastal fishing near reefs is the dominant small-scale fishery of Pitcairn and other Pacific islands (Dalzell et al., 1996) and is projected to be of the most effected by climate change (Bell et al., 2011). The reconstructed catch data can provide an insight into the fish targeted by different communities, for what purpose (subsistence or commercial) and the method of fishing. In combination with climate change projections, reconstructed catches can help craft an MPA such as the Pitcairn Island marine reserve that allows the local population to maintain coastal demersal and pelagic fishing, providing flexibility to change fishing tactics and target species whilst protecting the depletion of further offshore resources. In addition, historical catch reconstructions can provide understanding into the processes underlying an area's residuality to fishing, with a scope covering not only large-scale fisheries but also small-scale activities of great community importance. This information can be valuable for the establishment and management of marine protected areas, particularly in the face of changes to the selection and distribution of species targeted by small and large-scale fisheries.

AUTHOR CONTRIBUTIONS

AC and RW: Reconstruction and synthesis; TD and RI: Regional expertise; DZ: Supervision; MP: Biodiversity expertise.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <http://journal.frontiersin.org/article/10.3389/fmars.2017.00320/full#supplementary-material>

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